OPEN CLUSTERS IN THE GAIA-ESO SURVEY: TRACING THE CHEMICAL HISTORY OF THE MILKY WAY THIN DISK

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Abstract. The Gaia-ESO Survey (GES) is a large public spectroscopic survey that aims at observing with FLAMES@VLT the main stellar components of our Galaxy. The study of the population of open clusters is one of the main objectives of GES. We present some results from the first 18 months of observations, among them, a preliminary view of the radial metallicity gradient as traced by open cluster data and a comparison of the chemical patterns of clusters located in different parts of the Galactic disk.

1 Introduction

The Gaia-ESO Survey (GES) is a large public spectroscopic survey (240+60 nights, from the end of 2011 to the end of 2016) that observes with FLAMES@VLT the main stellar components of our Galaxy: the thin and thick disks, the bulge and the halo, and the population of open stellar clusters. More that 10^5 stars will be observed at the GES completion, mostly at a resolution of R$\sim$20 000 with GIRAFFE and a smaller percentage ($\sim10^4$ stars) with UVES at a higher resolution R=47000. The main characteristics and science goals of the Gaia-ESO Survey are described in Gilmore et al.(2012) and Randich et al.(2013). The main objectives include the study of Galactic chemo-dynamics, of cluster formation and evolution, and of stellar evolution.

2 The open clusters in GES

The GES expects to observe approximatively 70-80 open clusters with the purpose of obtaining a complete sampling of the parameter space: ages, distances to the Sun, Galactocentric distances (R_{GC}), masses, densities, and metallicities. The

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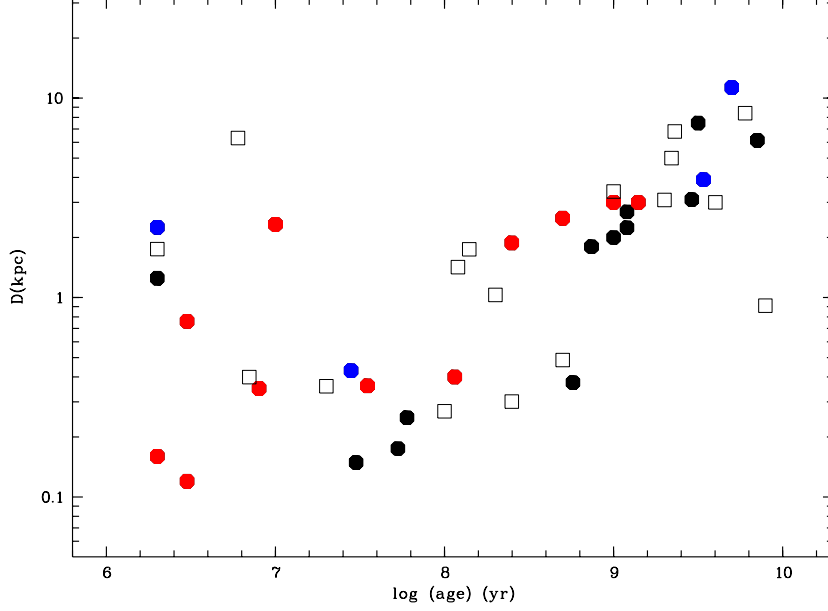
Fig. 1. Age (Gyr) versus Distance to the Sun (kpc) of the observed and proposed clusters for the next periods. The filled red circles represent the clusters released in IDR2, in blue in iDR3, and in black in iDR4. The empty squares show the clusters protected for the ESO observational periods P94 and P95.

proposed clusters cover large ranges both in ages and distances: they extend from very young star forming regions, young clusters with pre-main sequence stars, to intermediate-age and old clusters with more than 0.1 Gyr and reaching up to 8 Gyr; the Galactocentric range is well sampled with clusters located in the innermost part of the Galactic disk ($R_{GC} < 6$ kpc) to clusters located in the outskirts of our Galaxy ($R_{GC} \sim 17$ kpc). In Figure 1 we present the location in the age versus distance (from the Sun) plane of the observed clusters and of those protected for the next periods. The clusters located in the lower-left part of the figure are those mainly involved in the kinematics studies and have important legacy value with GAIA. The clusters in the upper part of the plot (D>1 kpc) are instead noteworthy for their application to the study of the radial metallicity gradient in the Galactic thin disk and its evolution with time.

3   The radial metallicity gradient as traced by open clusters

Open clusters are powerful probes of the conditions of the Milky Way Galaxy at all ages and in a wide range of locations in the disk. Their parameters (age, distance, reddening) are promptly available by, e.g., isochrone fitting of their colour-

magnitude diagrams, and have typical uncertainties of the order of 5-10%. They are indeed known to be amongst the most reliable tracers of the Galactic radial metallicity gradient, and, notably, of its time evolution.

The study of the radial metallicity gradient through open clusters sees the first pioneering work at the ends of the 70s, when Janes(1979), using the photometric metallicity determination of about 40 clusters located within 6 kpc from the Sun, derived, for the first time, a radial gradient of [Fe/H], with metallicity decreasing from the inner to the outer parts of the Galaxy at a rate d[Fe/H]/dR=−0.05 dex. During the following decades, many authors have tackled the argument, using gradually more accurate determination of the cluster parameters, and, especially, of their metallicity through low, medium and finally high resolution spectroscopy. A non-exhaustive list of works dedicated to the study of the Galactic gradient with open clusters includes Friel(1995), Friel et al.(2002), Yong et al.(2005), Sestito et al. (2006, 2008), Pancino et al.(2010), Heiter et al.(2014). Larger sampled including clusters of different ages allowed also to deal with the subject of the temporal variation of the radial gradient as, e.g., Chen et al.(2003), Magrini et al.(2009), Jacobson et al.(2011), Andreuzzi et al.(2011), Frinchaboy et al.(2013). Taking all together the literature results, the main achievements can be summarised in: *i)* the *global*, i.e. including clusters of all ages, gradient traced by open clusters shows a decreasing metallicity to a *breaking radius*, $R_{GC} \sim$10-12 kpc, and then it presents a plateau in metallicity at ∼-0.3 to -0.5 dex from the *breaking radius* to the most faraway clusters, i.e. ∼20-23 kpc (cf. Pancino et al.(2010) for a different view); *ii)* there is a notable dispersion in metallicity at any Galactocentric distance, typically of ∼0.5 dex; *iii)* concerning the time evolution of the gradient, there is a suggestion that younger clusters follow a flatter gradient than older clusters up to the breaking radius. However, due to the small number of clusters in different age bins, the slopes of the gradient at different ages are still sensitive to the selection of age bins and to the definition of the position of the *breaking radius* (cf., e.g., Magrini et al. 2009, Jacobson et al. 2011).

4   The GES contribution to the Galactic metallicity gradient

One of the main goals of the GES is the use of open clusters as tracers of the Galactic dick and, in particular, to define the shape of Galactic metallicity gradient, to investigate possible azimuthal and vertical gradients, and finally to asses their time evolution. In this framework, the selection of old and intermediate-age clusters to be observed by GES has been done to pursue also these objectives. In the first 18 month of observations, we have collected and analysed spectra of several young and old/intermediate-age clusters. The recommended stellar parameters and abundances of their stars have been distributed in the first data internal releases. Here we consider the most recent results, i.e. those of IDR2 and IDR3[1] of the UVES spectra. The results used in the present work are those of WG11 presented

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[1]IDR3 is an incremental release, fully consistent with IDR2

in Smiljanic et al.(2014). In Table 1 we present the main parameters of the clusters (coordinates, age, R_{GC}) and the metallicity derived from GES IDR2 or IDR3. For clusters whose GES data were already published we use parameters derived in the papers quoted in the last column. For NGC 6705, NGC 4815, and Tr 20 we refer to the metallicity of IDR2 as computed, for instance, by Tautvaišienė et al.(2014). For the remaining clusters, we used literature values for age and R_{GC}, and we derived a preliminary membership, based on radial velocities only, to compute their mean metallicity [Fe/H] from IDR2 or IDR3. In the last column we show the name of the release from which the radial velocities and metallicity are taken.

In Figure 2 we compare the GES results with a collection of high resolution spectroscopic data of open clusters (Magrini et al. 2009, 2010). From the Figure we note that, for the literature sample, the dispersion at each R_{GC} is quite significant, reaching the largest amplitude ∼0.5 dex around the *breaking radius*. Although the selected literature sample consists of only high resolution data, they are possibly affected by differences in the signal-to-noise of different samples, in the analysis technique, in the zero point that, altogether, might increase the dispersion. Thus, we might expect that, with a sample of clusters analysed in a fully homogeneous way, the artificial dispersion at each R_{GC} would be reduced and only the dispersion due to real effects would remain.

The present GES sample of IDR2/IDR3 is composed by a small number of clusters. However, it is already appreciable that the scatter at any radius is quite reduced. The maximum dispersion is obtained at Solar radius (∼0.2 dex) where more clusters were observed. However more clusters are necessary to asses the existence of the high dispersion present in the literature data at the breaking radius. Furthermore, the most distant cluster, Be 25, confirms the existence of a metallicity plateau in the outer Galaxy with important implications for the process of formation of disk galaxies (cf., e.g., Bresolin et al. 2009).

5   The clusters' chemical patterns

The high resolution UVES spectra allow to derive the abundances of a large variety of chemical elements, belonging to different nucleosynthesis channels. They permit us to compare in a fully consistent way the detailed chemical patterns of open clusters located in different part of our Galaxy. In Figure 3 we show the chemical patterns of mainly old and intermediate-age clusters (only NGC 2547 among the clusters younger than 0.1 Gyr is considered here) of Table 1. In the x axes we show the atomic numbers and in the y axes the average cluster abundances over iron, [El/Fe]. The elements presented in the plot can be grouped in α-elements (O, Mg, Si, Ca, Ti) –produced by massive stars in SNII explosions–, iron-peak elements (Sc,Va, Cr, Ni) –produced mainly by SNIa–, and neutron-capture elements (Y, and Eu)–produced by low/intermediate-mass stars (Y) or by massive stars (Eu). Although limited by small statistics, we note that groups of clusters located at similar R_{GC} share similar chemical patterns. Remarkable differences are seen for some abundance ratios, for instance, in NGC 6705 with respect to the other inner-disk clusters (cf. Magrini et al. 2014). However, many similitudes are present in

Table 1. Clusters' parameters

Name	RA	dec	Age	R_{GC}(a)	[Fe/H]	Ref.
	J2000.0		(Gyr)	(kpc)		
Be 81	19:01:36	-00:31:00	0.86±0.1	5.4	+0.23±0.08	Magrini et al. (in prep.)
NGC 6705	18:51:05	-06:16:12	0.30±0.05	6.3	+0.00±0.05(*)	Cantat-Gaudin et al.(2014), Tautvaisiene et al.(2014)*
Tr 20	12:39:32	-60:37:36	1.50±0.15	6.9	+0.10±0.08(*)	Donati et al.(2014), Tautvaisiene et al.(2014)*
NGC 4815	12:57:59	-64:57:36	0.57±0.07	6.9	-0.01±0.04(*)	Friel et al. (2014), Tautvaisiene et al.(2014)*
Cha I	11:06:48	-77:18:00	0.002	8	-0.10±0.04	Spina et al.(2014b)
γ^2 Vel	08:09:32	-47:20:12	0.008	8	-0.06±0.02	Spina et al.(2014a)
Rho Oph	16:28:00	-24:25:30	0.003	7.9	-0.09±0.02	Spina et al.(in prep.)
NGC 2264	06:40:58	+09:53:42	0.003	8.8	-0.09±0.05	Spina et al.(in prep.)
NGC 2547	08:10:00	-49:12:00	0.003	8.1	-0.03±0.06	Spina et al.(in prep.)
NGC 2516	07:58:04	-60:45:11	0.12	7.9	+0.08±0.03	idr2
IC 4665	17:46:18	+15:43:00	0.004	8.2	-0.01±0.03	idr3
NGC 2243	06:29:34	-31:17:00	4.7	11	-0.43±0.03	idr3
Be 25	06:41:00	-16:31:00	4.5	17	-0.24±0.03	idr3

(a) computed with $R_{\odot}$= 8 kpc; (*) [Fe/H] from Tautvaisiene et al.(2014).
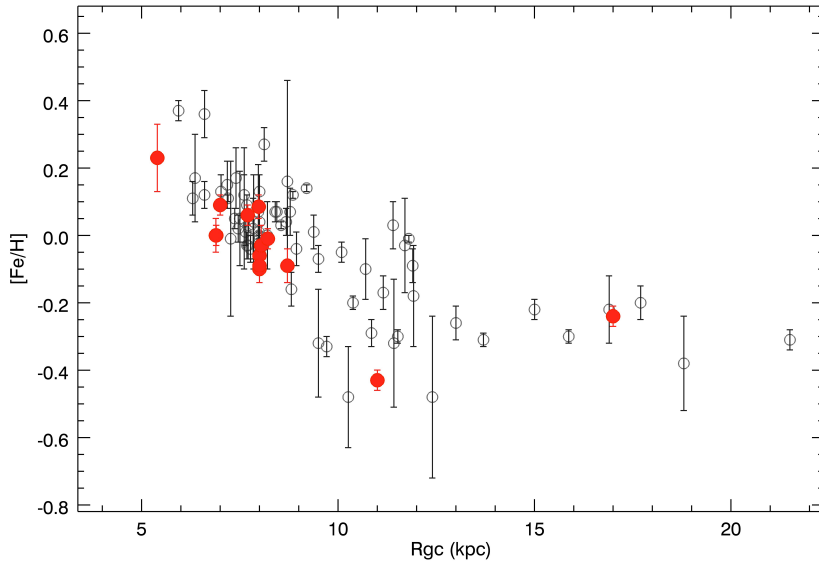
Fig. 2. The radial metallicity [Fe/H] gradient as traced by open clusters. Red circles show the open clusters observed by GES in idr2 and idr3, empty circles are a collection of literature high resolution spectroscopic data from Magrini et al. (2009, 2010).
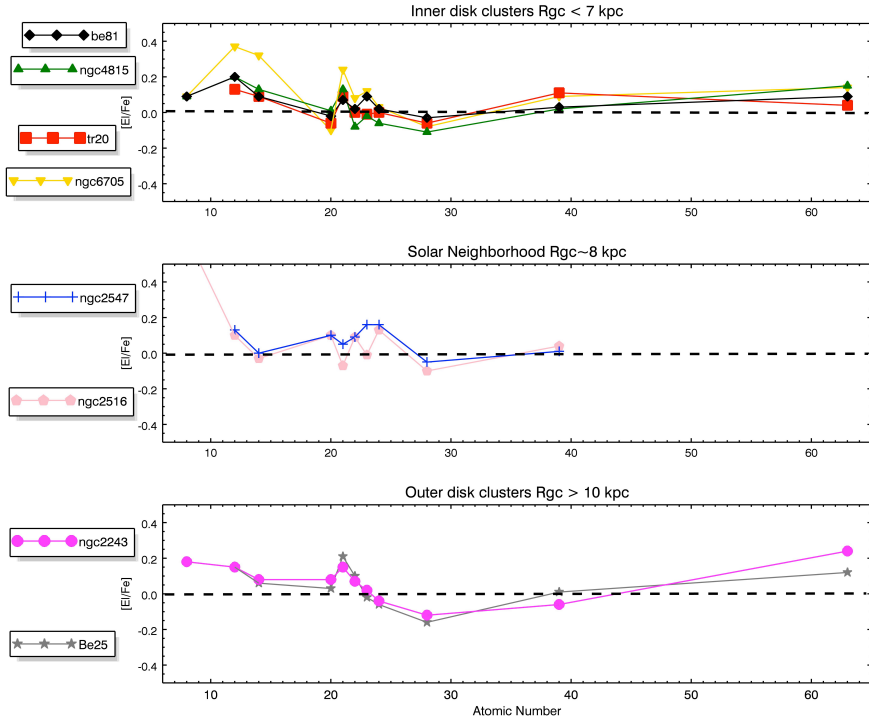
Fig. 3. Chemical pattern of old/intermediate-age clusters: atomic numbers (oxygen–8, magnesium–12, silicon–14, calcium–20, scandium–21, titanium–22, vanadium–23, chromium–24, nickel–28, yttrium–39, europium–63) vs. average cluster abundances [El/Fe]. Clusters are divided on the bases of their R_{GC}: in the upper panel the inner disk clusters, in the central panel the solar neighbourhood clusters, and in the lower panel the outer disk clusters.

the patterns of the three groups. Particularly surprising is the comparison of the two outer disk clusters that, notwithstanding the large difference in R_{GC}, show a striking likeness, a possible signature of the homogeneity, not only in iron, of the outer disk of the Milky Way galaxy.

6   Conclusions

The open clusters observed during the first 18 months of the Gaia-ESO Survey are showing a great potentiality for the study of the abundance distribution in the Milky Way thin disk. They trace a well-defined gradient in the inner part of the disk with a dispersion <0.2 dex at each R_{GC}. The farthest cluster, Be 25, confirm the existence of an outer metallicity plateau. The variety of elements available from the UVES analysis allows tracing the chemical patters of clusters located in

different regions of the disk. Grouping clusters in distance bins has allowed us to discover remarkable similitudes in their chemical patters that are hints of the Galactic radial enrichment history.

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